Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 102 (2015) 1056 – 1063

Procedia Engineering

www.elsevier.com/locate/procedia

The 7th World Congress on Particle Technology (WCPT7)

AN EXPERIMENTAL STUDY ON A HORIZONTAL ENERGY-SAVING PNEUMATIC CONVEYING SYSTEM

Fei YAN[a]*, Akira RINOSHIKA[b]

[a] *School of Mechanical Engineering, Jiangsu University of Science and Technology, MengXi Road No.2, Zhenjiang, 212003, China*
[b]*Department of Mechanical Systems Engineering,Graduate School of Science and Engineering, Yamagata University 4-3-16 Jonan, Yonezawa-shi, Yamagata 992-8510, Japan*

Abstract

In order to reduce power consumption and conveying velocity, a new pneumatic conveying system where soft fins are horizontally mounted on the center plane of pipe in the front of inlet is proposed in this paper. The experimental study focuses on the effect of the different fin's lengths on the horizontal pneumatic conveying system in terms of frequency characteristics of fin's oscillation, pressure drop, conveying velocity, power consumption and particle flow pattern. Comparing with the conventional pneumatic conveying, the pressure drop, minimum and critical velocities and power consumption can be reduced by using soft fins in lower air velocity range. The effective of fin is quite evident with increasing the length of fin. The maximum reduction rates of the minimum velocity and power consumption by using soft fins are about 14.8% and 25.5%, respectively.

Selection and peer-review under responsibility of Chinese Society of Particuology, Institute of Process Engineering, Chinese Academy of Sciences (CAS)

Keywords: fin; minimum and critical velocities; particle flow pattern; Pneumatic conveying system; power consumption; pressure drop;

1. Introduction

The pneumatic conveying is frequently operated in the dilute-phase regime or in the high air velocity region and cause higher power consumption, pipe erosion and particle degradation. Therefore even small reductions in pressure drop and conveying velocity can obtain dramatic improvements in energy-saving, pipe wear and particle degradation. Then as an important design criterion, the pneumatic conveying should keep the pressure drop and conveying velocity as low as possible. In order to reach this purpose, some energy-saving techniques have been

* Corresponding author. Tel&Fax:+86-0511-8440-1142;
E-mail address: yanfei991314@163.com

1877-7058
Selection and peer-review under responsibility of Chinese Society of Particuology, Institute of Process Engineering, Chinese Academy of Sciences (CAS)
doi:10.1016/j.proeng.2015.01.228

developed. Tomita and Asou [1] applied successive slug flow which reaches a minimum of the power consumption in the low-velocity region, a minimum that is lower than the minimum of the suspension flow region. Wypych and Yi [2] present results from investigations into the capacity limitation of low-velocity slug-flow pneumatic conveying. And the mechanism for the formation of the unstable zone also was explored experimentally and theoretically. A new theoretical model based on observed unstable flow mechanisms and stability criteria was presented for the purpose of predicting transport boundaries. Sing et al [3] used the weight-loss method to measure the minimum pick-up velocities for entrainments of particle mixtures having binary particle size distributions. The Venturi feeder conveying solids without moving parts was used as an efficient conveying device in pneumatic conveying system [4]. Ueda et al. [5] developed an ejector type of particle feeder, which generates a spiral flow in the downstream pipeline, and have successfully applied this feeder in the dilute-phase pneumatic conveying. Watanabe [6] used a spiral tube as the conveying pipeline for preventing unstable flows and blockage in the dense-phase pneumatic conveying. Kalman et al. [7] investigated the pickup mechanism in a layer of particles, and they found that the range of pickup velocities can be divided into three zones of behavior that can be described accurately by developing simple relations between the Reynolds and Archimedes numbers. Li and Tomita [8, 9] applied the swirling flow to pneumatic conveying system for reducing power consumption. Their studies concluded that the application of swirling flow could reduce the critical and minimum conveying velocities, the pressure drops, the fluctuations in the wall static pressure, and the power consumption as compared to the equivalent experimental rigs employing conventional axial flow pneumatic conveying.

In this paper, a new pneumatic conveying system where soft fins are mounted on the front of the inlet of the gas-particle mixture is proposed for reducing the conveying velocity and power consumption further. The experimental study focuses on the effect of the mounted soft fins on the horizontal pneumatic conveying system in terms of the pressure drop, conveying velocity, power consumption and particle flow pattern.

2. Experimental apparatus and procedure

2.1. Experimental apparatus

The experimental facility of the positive pressure conveying system, as shown in Fig.1, is used in the present study. Air from a blower flows through the calibrated nozzle, and picks up the solid materials fed by gravity from the feed tank at the inlet of the conveying pipeline. Then, the gas-particle mixture enters the test pipeline and at the pipeline exit the particles are separated by the separator. The conveying pipeline consists of a horizontal smooth acrylic tube with an inside diameter of D = 80 mm and total length of about L = 5 m. The airflow rate and the solids mass flow rate are respectively measured by the orifice meter and load cell. The gauge pressures along the pipeline are measured by pressure transducers.

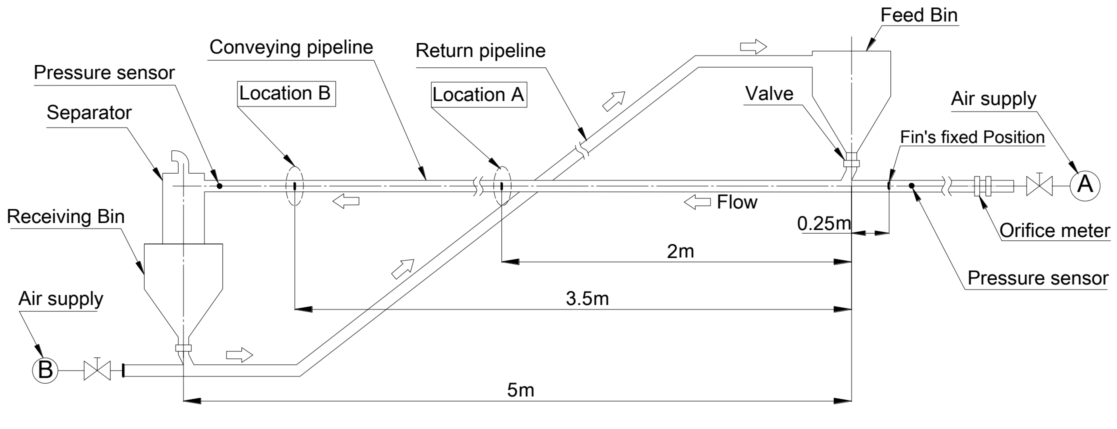


Fig. 1. Schematic diagram of the experimental apparatus.

Two kinds of the polyethylene particles that their properties are given in Table 1 are used as conveying material in this experiment. The superficial air velocity U_a is fixed at varied from 10 to 17 m/s, the mass flow rate of solids G_s is varied from 0.20 to 0.45 kg/s.

Table 1. Properties and dimensions for tested particles

Shape	Average diameter (mm)	Density (kg/m^3)	Floating velocity (m/s)
Cylindrical	2.3	978	7.5
Discal	3.3	952	8.6

2.2. Soft fins

In order to excite flow oscillation and generate vertical component of air velocity, four pieces of the soft fins made of polyethylene, as shown in Fig.2a, are horizontally mounted on the center plane of pipe in the front of inlet (Fig.2b). In this case the soft fins oscillate up and down as the air flows over them. Three kinds of soft fins having different lengths (200, 250 and 300mm) and the same width of 20 mm, called SF200, SF250 and SF300 respectively, are used. When conveying particles, the oscillating fins of SF300 directly touch particles that are fed from the feed tank at the inlet of the conveying pipeline. The other soft fins (SF200 and SF250) are just oscillated up and down by air flow.

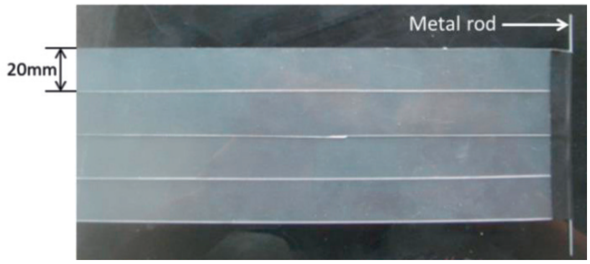


Fig.2(a).Soft fins.

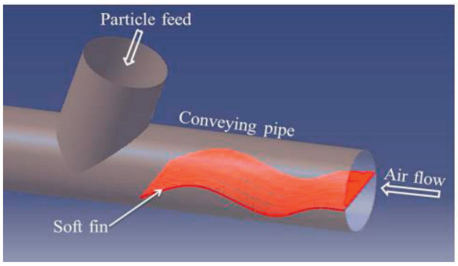


Fig.2(b).Mounted soft fins.

3. Experimental results and discussions

3.1. Total pressure drop and power consumption for different lengths of fin

In order to compare with conventional pneumatic conveying, the pressure drop due to the soft fins should be included. Here the pressure drop Δp between the inlet of air flow and exit of the conveying pipe are considered. To evaluate the power consumption of pneumatic conveying systems, the power consumption coefficient E, which is calculated from the pressure drop Δp, solids flow rate G_s and the airflow rate Q_a, is used according to the following equation:

$$E = \frac{\Delta p Q_a}{g G_s L}$$

where g is the gravity acceleration and L is the total length of conveying pipeline. In this study, the air velocity at the minimum pressure drop is defined as the minimum velocity. The critical or choking velocity is defined as the air velocity at which strong pressure fluctuations appear. These pressure fluctuations are accompanied by flow instability, which makes it impossible to continuously convey particles. We measured the air flow rate at the threshold of instability. These two velocities (the minimum velocity and critical or choking velocity) are of particular importance in the design of a pneumatic conveying system.

Figure 3 shows the pressure drop Δp versus the air velocity U_a with different lengths of soft fins as a parameter when conveying particles of d_p=2.3 mm by G_s=0.25 and 0.45kg/s. It is evident that as the air velocity decreases the pressure drops of all cases (both fins and non-fin) first decrease and then increase after the minimum pressure drop.

Comparing the different lengths of fins with the conventional pneumatic conveying, the pressure drops with fins are higher than that without fin in the range of high air velocity and are independent on the length of fin. However, the pressure drops with fins become lower than that without fin in the range of low air velocity. Furthermore, the minimum and critical velocities are largely decreased by using fins comparing with the conventional pneumatic conveying. As increasing the length of fins or decreasing G_s, the reduction rate of the pressure drop and minimum and critical velocities become apparently large at low air velocity. This is because the air flow of the inlet is oscillated due to the fins' vibration and generates the vertical component of air velocity so that the particles are easily suspended and accelerated. Among the five kinds of fins, the longest fin(SF300) exhibits the lowest pressure drop and the lowest minimum and critical velocities for all G_s. The maximum reduction rate of the pressure drop and minimum velocity by SF300 are about 13.6% and 4.23% for the G_s=0.25kg/s and 0.45 kg/s, respectively. Since the oscillating SF300 directly touch particles that are fed from the feed tank at the inlet of the conveying pipeline, particles are easily dispersed and accelerated and the deposition of particles on the bottom of the pipeline can be avoided even for low air velocity.

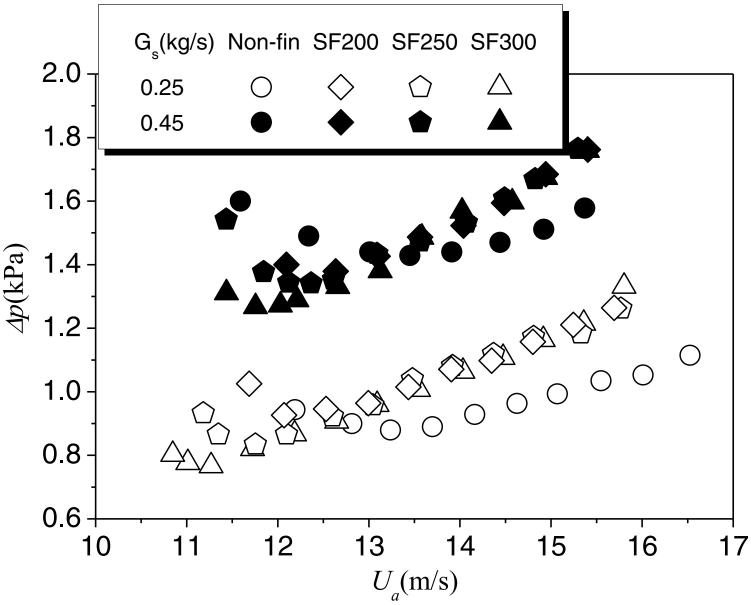


Fig. 3. Comparison of pressure drop between different lengths of fins and non-fin when conveying particles of d_p=2.3 mm.

In order to examine the effect of particle diameter, the particles of d_p= 3.3 mm having a relative large floating velocity is applied to the pneumatic conveying. The pressure drop Δp versus the air velocity U_a with different lengths of soft fins as a parameter for G_s=0.20 and 0.40 kg/s is shown in Fig. 4. It is observed that the pressure drop and minimum and critical velocities are also reduced in the low air velocity region by using fins for G_s=0.20 kg/s (except for SF200), but the pressure drops have not evidently reduction for G_s=0.40 kg/s.

3.2. Minimum conveying velocity

Figure 5 shows the difference of the minimum conveying velocities with the change of fin's length. It is clearly seen that Fin300 exhibits the lowest minimum and critical velocities for all cases. For the particle d_p = 2.3 mm, the maximum reduction rate of the minimum conveying velocity by Fin300 is about 14.8% and 14% for the G_s = 0.25 kg/s and 0.45 kg/s, respectively. For the particle d_p = 3.3 mm, the maximum reduction rate of the minimum conveying velocity by Fin300 are about 12.8% and 6.2% for G_s = 0.20 and 0.40kg/s, respectively.

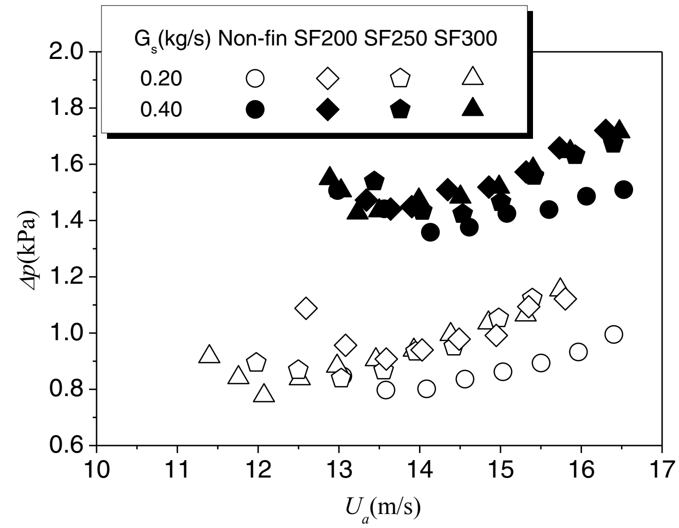


Fig. 4. Comparison of pressure drop between different lengths of fins and non-finwhen conveying particles of d_p=3.3 mm.

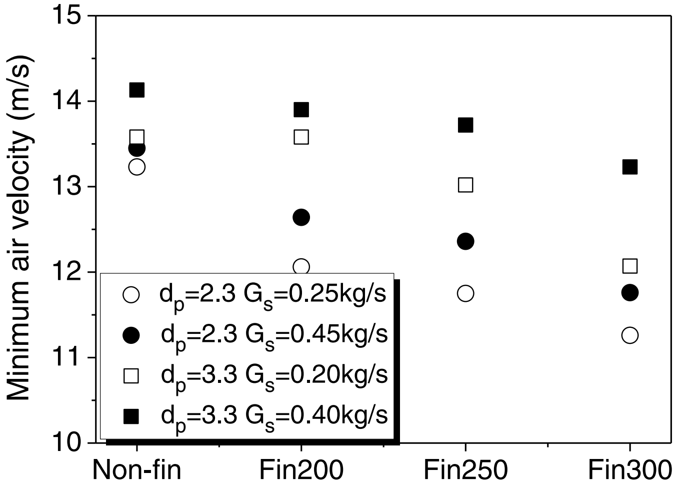


Fig. 5. Minimum conveying velocity versus fin's length.

3.3 Power consumption for different lengths of fin

Figure 6 illustrates the power consumption coefficient E for particles of d_p=2.3 mm versus air velocity with different lengths of fins as a parameter for G_s=0.25 and 0.45 kg/s. At high air velocity E with fins is larger than that without fin and is independent on the length of fin. Below the air velocity of the minimum E (non-fin), however, E with fins becomes smaller than that of non-fin, and E decreases as increasing the length of fin. Comparing with the conventional pneumatic conveying, the maximum reduction rate of power consumption by SF300 are about 25.5% and 13% for G_s=0.25and 0.45 kg/s, respectively.

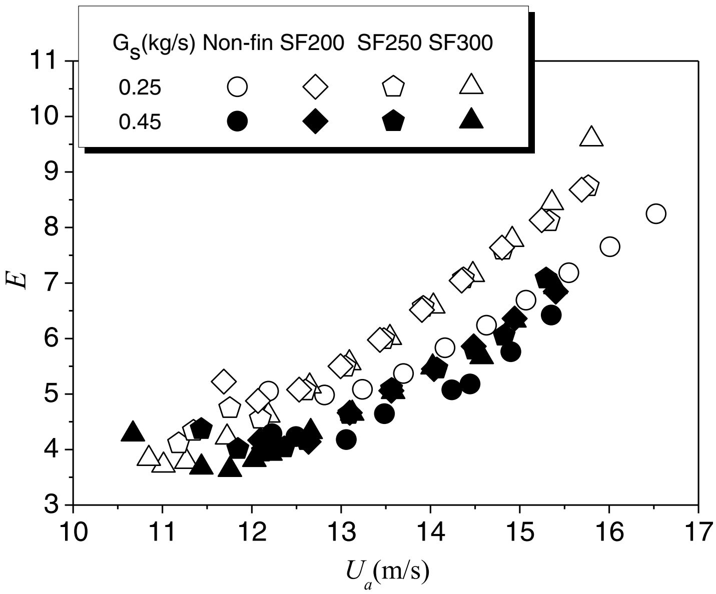


Fig. 6. Comparison of power consumption between different lengths of fins and non-fin when conveying particles of d_p=2.3 mm.

Figure 7 shows a comparison of the power consumption coefficient E between different lengths of fins and non-fin when conveying particles of d_p=3.3 mm. For G_s=0.20 kg/s, the power consumption coefficient E of short fins of SF200 is larger than that of non-fin. However, the power consumption is reduced by SF220, SF250 and SF300 in the low air velocity region. The maximum reduction rate of power consumption coefficient E is about 15.8% by using SF300.

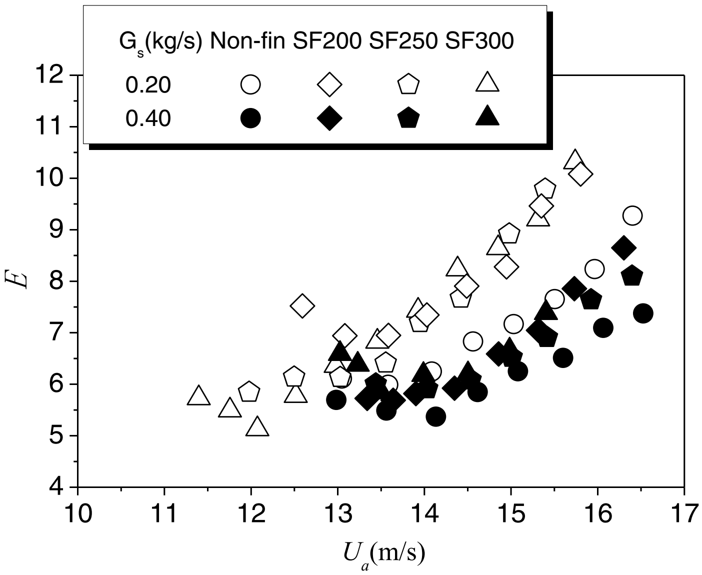


Fig. 7. Comparison of power consumption between different lengths of fins and non-fin when conveying particles of d_p=3.3 mm.

In the case of G_s=0.40 kg/s, the power consumption coefficients E of fins are larger than that of non-fin in all velocity region. It is because the particles of d_p=3.3mm have a large floating velocity and need larger force to suspend in low air velocity.

Above results indicate that using soft fins is more effective for reducing the pressure drop, power consumption and the conveying velocity in the horizontal pneumatic conveying. The effective of fin becomes quite evident with increasing the length of fin. Conveying the particles of d_p= 2.3mm by using the soft fins exhibits more effective than that of particle d_p=3.3mm.

3.4. Flow patterns of particles for different lengths of fins

In order to compare the different lengths of fins with non-fin in conveying particles, the flow patterns of particles were visualized at locations of 0.3 m from the particle inlet by high-speed camera.

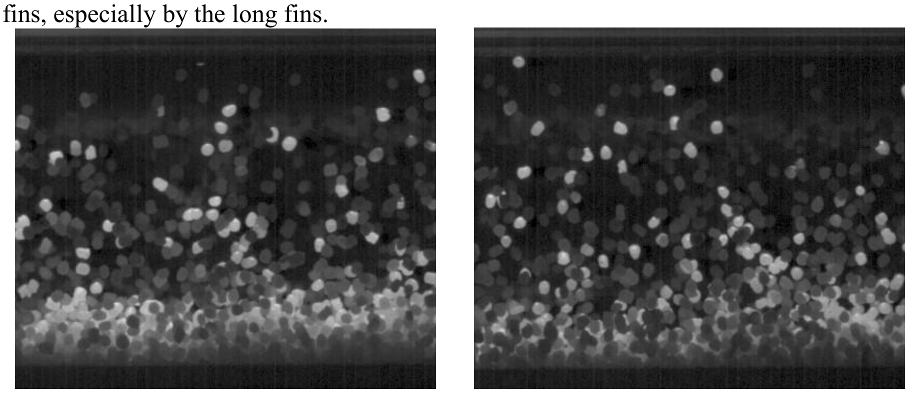
Fig.8 shows particle flow patterns at a location of 0.3m (acceleration region) by using different lengths of fins and non-fin when conveying particles of d_p=2.3 mm (U_a=11～13 m/s, G_s=0.45 kg/s).

For conventional pneumatic conveying of U_a=13.45m/s, as shown in Fig.8(a), the particle sediments appear on the bottom of the pipeline, over which the particles strand slide along. It is observed that the sediments are apt to form near the inlet of particle feed or in the particle acceleration region. As air velocity decreases, this sediment grows up and results in threatens blockage easily.

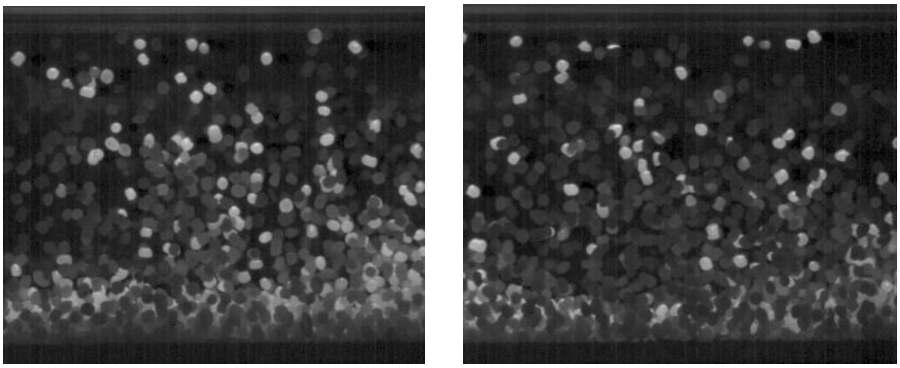
To remove the sediments and reduce the conveying velocity, the different lengths of soft fins (SF200, SF250 and SF300) are horizontal mounted on the center plane of the conveying pipeline before the inlet of particle feed.

Figure 8(b) and (c) shows the particle flow patterns of SF200 at U_a=12.6m/s.It is observed that the particle sediments disappear and the all flow patterns exhibit particle suspensions with a higher particle concentration along the bottom of the pipeline even for lower conveying velocity than that of non-fin. This is because the oscillation of air flow, excited by fins, generates the vertical component of air velocity. Therefore the particles are easily suspended and dispersed, and the deposition of particles on the bottom of the pipeline is avoided even for low conveying velocity.

As increasing the length of fins to Fin250 and Fin300, the particle flow patterns at U_a=12.1 and 11.8m/s are shown in Fig.8(c)-(d).Comparing with Fin200 (Fig.8b), the particle concentration near the bottom of the pipeline decreases with increasing the length of fins and particle flow pattern of Fin300 is similar to fully suspended phase flow. One reason for this effective is that the long fins can cause large oscillation of air flow. On the other hand since Fin300 directly touch particles that are fed from the feed tank at the inlet of the conveying pipeline, particles are more easily suspended and dispersed. Therefore, the pressure drop and minimum and critical velocities can be reduced by the fins, especially by the long fins.



(a) Non-fin (U_a=13.45m/s) (b) SF200 (U_a=12.6m/s)



(c) SF250(U_a=12.1m/s) (d) SF300 (U_a=11.8m/s)

Fig.8 Particle flow patterns for different lengths of fins and non-fin at a location of 0.3 m from the particle inlet when conveying particles of d_p= 2.3 mm（G_s=0.45 kg/s）

4. Conclusions

(1) The pressure drop, minimum and critical velocities and power consumption can be reduced by using soft fins in the range of low air velocity.
(2) The effective of fin is quite evident for conveying small particles or with increasing the length of fin.
(3) The maximum reduction rates of the minimum velocity and power consumption by using soft fins are about 14.8% and 25.5%, respectively.
(4) Visualization of the particle flow pattern reveals that the particle concentration near the bottom of the pipeline decreases with increasing the length of fins near their minimum velocity. Especially the particle flow pattern of SF300 is similar to fully suspended phase flow.

References

[1] P. G. Sing, W. C. Jia, H. Kunn, Effects of binary particle size distribution on minimum pick-up velocity in pneumatic conveying, Powder Technology, 208 (2010), pp.166-174.
[2] Y. Tomita, H. Asou, Low-velocity pneumatic conveying of coarse particles in a horizontal pipe, Powder Technol. 196 (2009) 14 – 21.
[3] P. W. Wypych, J. L. Yi, Minimum transport boundary for horizontal dense-phase pneumatic conveying of granular materials. Powder Technology, 129 (2003) 111-121.
[4] D. Mills, Pneumatic conveying design guide, Butterworth-Heinemann, London, 2004.
[5] H. Ueda, M. Sakai, K. Horii, K. Funatsu, Y. Tomita, Study of swirling pneumatic transport of granule in a horizontal pipe (in Japanese), Trans. JSME B-67 (2001)
[6] K. Watanabe, Transport of solids by pipelines with spiral tube, ASME 234 (1995) 57–64.
[7]H. Kalman, A. Satran, D. Meir, E. Rabinovich, Pickup (critical) velocity of particles. Powder Technology 160 (2005) 103 – 113.
[8] H. Li and Y. Tomita, An experimental study of swirling flow pneumatic conveying system in a horizontal pipeline, Trans. ASME, J. Fluids Eng. 118 (1996) 526-530.
[9] H. Li and Y. Tomita, An Experimental Study of Swirling Flow Pneumatic Conveying System in a Vertical Pipeline, Trans. ASME, J. Fluids Eng., 120(1998), pp. 200-203.